

# Economic valuation of the impacts of climate change in agriculture in Europe

Quiroga S.<sup>1</sup>, Iglesias A.<sup>2</sup>

<sup>1</sup> Department of Statistics, Economic Structure and I.O., Universidad de Alcalá, Madrid, Spain. e-mail: sonia.quiroga@uah.es

<sup>2</sup> Department of Agricultural Economics and Social Sciences, Universidad Politécnica de Madrid, Spain. e-mail: ana.iglesias@upm.es

**Abstract—** The objective of this study is to provide a European assessment of the potential effects of climate change on agricultural crop production computing monetary estimates of these impacts for the European agricultural sector. The future scenarios incorporate socio economic projections derived from several SRES scenarios and climate projections obtained from global climate models and regional climate models. The quantitative results are based simulations using the GTAP general equilibrium models system that includes all relevant economic activities. The estimated changes in the exports and imports of agricultural goods, value of GDP and crop prices under the climate and socio-economic scenarios show significant regional differences between northern and southern European countries. The patterns are positive effects except on Mediterranean countries. The most important increases seem to concern the continental region, where the productivity increases enlarge GDP more intensively due to the importance of agricultural sector in the region. The monetary estimates also show that in all cases uncertainty derived from socio-economic scenarios has a larger effect than the ones derived from climate scenarios.

**Keywords—** agriculture, climate change, computable general equilibrium models.

## I. INTRODUCTION

European agricultural policy faces some serious challenges in the coming decades. The most striking of these are competition for water resources, rising costs due to environmental protection policies, competition for international markets, loss of comparative advantage in relation to international growers, climate change and the uncertain in effect of the current European policies as adaptation strategies. Demographic changes are altering vulnerability to water shortages and agricultural production in many areas, with potentially serious consequences at local and regional levels. Population and land-use dynamics, and the overall policies for environmental

protection, agriculture, and water resources management, determine, and limit, possible adaptation options to climate change.

An improved understanding of the climate-agriculture-societal response interactions is highly relevant to European policy since according to the IPCC Fourth Assessment Report (IPCC, 2007), climate change is already happening, and will continue to happen even if global greenhouse gas emissions are curtailed. There is now concern that global warming has the potential for affecting the climatic regimes of entire regions (IPCC, 2007). The effects of climate change on agriculture vary between different regions and different scales (global, regional and local). Many studies document the implications of climate change for agriculture and pose a reasonable concern that climate change is a threat to poverty and sustainable development, especially in marginal areas. Nevertheless, the relationships between climate change and agriculture are complex, because they involve climatic and environmental aspects (physical effects) and social and economic responses.

The Stern Review of the Economics of Climate Change (Stern et al., 2006) argues that “the overall costs and risks of climate change will be equivalent to losing at least 5% of global GDP each year. This has been challenged by many economists with large working experience in climate change (Tol, 2007) since it ignores and contradicts numerous unquestionable results (Nicholls and Tol, 2005; Nordhaus, 2006; Sachs, 2001; Fankhauser and Tol, 2005). Economic impacts of climate change have proved more difficult to project than the future climate itself.

The effects of climate change in regional, national, or global agricultural economy have been analysed by using several types of economic models in order to

estimate the potential impacts of climate change on production, consumption, income, gross domestic product (GDP), employment, and farm value (Darwin, 2004; Kaiser et al., 1993; Reilly et al., 2003). For agricultural impact assessment, the models allocate domestic and foreign consumption and regional production based on given perturbations of crop production, water supply, and demand for irrigation derived from biophysical techniques. Population growth and improvements in technology are set exogenously. These models measure the potential magnitude of climate change impacts on the economic welfare of both producers and consumers of agricultural goods. The predicted changes in production and prices from agricultural sector models can then be used in general equilibrium models of the larger economy.

Computable General Equilibrium (CGE) models comprise a representation of all major economic sectors, empirically estimated parameters and no unaccounted supply sources or demand sinks. In general equilibrium models countries are linked through trade, world market prices and financial flows, and change in relative prices induce general equilibrium effects throughout the whole economy. Although partial equilibrium models make it possible to estimate the costs of policy measures, taking substitution processes in production and consumption as well as market clearing conditions into account, CGE models additionally allow for adjustments in all sectors, enable to consider the interactions between the intermediate input market and markets for other commodities or intermediate inputs, and complete the link between factor incomes and consumer expenditures (Conrad, 2001).

The objective of this study is to provide monetary estimates of the impacts of climate change in European agricultural sector.

## II. METHODS AND DATA

### A. Approach

The response of crop production to climate change is driven by changes in crop yields as this strongly

influences farmer decisions about profitability. Crop yields respond to climate change through the direct effects of weather, atmospheric CO<sub>2</sub> concentrations, and water availability. Iglesias et al. (2007) estimated crop production functions at the regional level taking into account water supply and demand, social vulnerability and adaptive capacity. The functional forms for each region represent the realistic water limited and potential conditions for the mix of crops, management alternatives, and endogenous adaptation to climate characteristic of each area. Here we take the changes in crop under several climate and socio-economic scenarios and use them as inputs for the monetary evaluation. Future climate change scenarios are driven by changes in socio-economic variables (i.e., population, technology, economic development, etc) that result in different greenhouse gas emissions (i.e., CO<sub>2</sub> and other gases). These changes are then used as inputs to global climate models to project changes in climate conditions. The scenarios considered in this study were developed for the PESETA project (PESETA, <http://peseta.jrc.es/index.htm>).

### B. Changes in crop production

Changes in crop production were estimated at the regional and country level based in the Europe-wide spatial changes in crop production and agricultural zones provided by Iglesias et al (2007). Adaptation was explicitly considered and incorporated into the results by assessing country or region's potential for reaching optimal crop yield. Optimal yield is the potential yield given non-limiting water applications, fertilizer inputs, and management constraints. Adapted yields are evaluated in each country or region as a fraction of the potential yield. The weighting factor combines the ratio of current yields to current yield potential and current growth rates in crop yields and agricultural production.

### C. Socio-economic and climate change scenarios

Two climate scenarios were used in the study (Table 1), constructed as a combination of Global Climate Models (Had CM3 and ECHAM4) downscaled for Europe with the HIRHAM and RCA3 regional models and driven by the SRES A2 socio-

economic scenario (Table 1). The scenarios were derived from the data provided by the PRUDENCE project (PRUDENCE, 2006)

Table 1 Summary of the climate scenarios used in the study

Scenario	Time frame	Driving Socio-economic scenario SRES	Driving Global climate models (GCM)	Regional climate
HadCM3	2071-2100	A2	HadCM3	DMI/HIR HAM
ECHAM4/O PYC3	2071-2100	A2	ECHAM4	SMHI/RC A3

#### D. General equilibrium model

For the CGE simulation we use the GTAP general equilibrium model system (Hertel, 1997) calibrated in 2001 (GTAP 6 database), which is the global data base representing the world economy for 2001 year. Dimaranan and McDougall (2006) expose the regional, sector and factors aggregation of the data base.

The general equilibrium approach of GTAP includes broadly all relevant economic activities. Financial flows as well as commodity flows at the international level are consistent in the sense that they balance. The countries are linked through trade, world market prices and financial flows. The system is solved in annual increments, simultaneously for all countries.

#### *Regional, sector and factor aggregation:*

In our simulation, the model aggregation considers 7 regions, 3 sectors and 4 factors. The 87 GTAP regions were mapped to seven European regions and a macro region integrating the rest of world (ROW). For the European regions we consider the EU-countries of the Olesen and Bindi (2002) regional aggregation. This approach divides Europe into seven major agricultural regions determined by both environmental and socio-economic factors. Table 2 shows the regional aggregation.

Table 2 Summary of the regional aggregation

Agricultural region	Countries included
Boreal	Finland, Sweden
Atlantic North	Ireland, United Kingdom
Atlantic Central	Belgium, Denmark, Germany, Luxembourg, The Netherlands
Alpine	Austria
Continental	Czech Republic, Estonia, Latvia, Lithuania, Poland, Slovakia, Bulgaria, Croatia, Hungary, Romania, Slovenia
Mediterranean North	France, Portugal
Mediterranean South	Cyprus, Greece, Italy, Malta, Spain

The 57 GTAP sectors were aggregated into 3 new sectors which detailed components are in Table 3. The factors considered are Land, Labour (including unskilled and skilled labour), Capital and Natural Resources (Energy).

Table 3 Summary of the sectors

Sector	Components
Crops	Paddy rice, wheat, cereal grains, processed rice, vegetables, fruits and nuts, oil seeds, sugar cane and sugar beet, plant based fibres, crop mix, vegetable oils and fats and sugar
Other agrarian goods	Wool, silk-worm cocoons, meat: cattle, sheep, goats and horse, meat products, food products, beverages and tobacco
Manufactures	Manufacture GTAP sectors
Services	Services GTAP sectors

#### *Changes in crop production:*

Following Bosello and Zhang (2005), we first pseudo-calibrate the model, deriving a baseline equilibrium “without climate change”. For this purpose, we used population increase and technological change as key variables for the baseline

projections. We also pseudo-calibrate a “without global change” baseline considering the most adaptive scenario B1 as the no-change scenario. We consider this projection to decompose the global change into climate and socio-economic signals. In the second step, we evaluate the climate change physical impacts on agriculture, using the GTAP general equilibrium model (Hertel, 1997) calibrated in 2001. For the increase in population we considered the downscaled population data from IIASA projections.

As it is revised on Grubb et al. (2002), there is no consensus on the technological change modelling. Macroeconomic environmental models such as GREEN, GEM-E3 and G-cubed have a constant autonomous energy efficiency improvement, typically in a range of 0.5-2.5% a year, while the DICE model has an exponential slowdown in productivity growth (1-edt) starting from a base of 1.41% per year in 1965 with the constant  $d$  set at 0.11 per decade. In our model, we first use the DICE approach for technological change modelling, starting from the base of 1% per year in 2001 and the same constant  $d$  per decade.

In a second step, we implement the physical impacts on European agriculture reported by PESETA project. (EU Commission, 2007 and <http://peseta.jrc.es> for further information and the complete report on physical impacts). These impacts were estimated at the grid level and aggregated over agroclimatic areas, so to integrate it at the GTAP model it has been necessary to aggregate into country level. The aggregated effects were calculated as a weighted average taking into account the weight of different agroclimatic areas on each European region. For consistency the rest of the world region could also experience a change in productivity, so we considered the average crop yield changes for the world calculated on Parry et al. (2004) for the HadCM3 and A2 scenario. The productivity shock has been introduced in GTAP as land-productivity- augmenting technical change over crop sector in each region. We also include the increase in population projected for each considered scenario (A2).

### *E. Estimating the climate and the socio-economic signal*

The study considered changes derived from the climate signal alone and changes derived from the socio-economic signal alone. In order to estimate the later ones, the reference population scenario for the future was taken from the B1 SRES scenario. This choice was justified since the B1 SRES scenario is the one that presents a moderate population increase closer to UN and Wold Bank estimates. Figure 1 summarises the rationale of the estimation of the climate signal alone and the socio-economic signal alone. It is important to notice that the socio-economic signal for a particular country or region may be positive or negative depending on the timeframe.

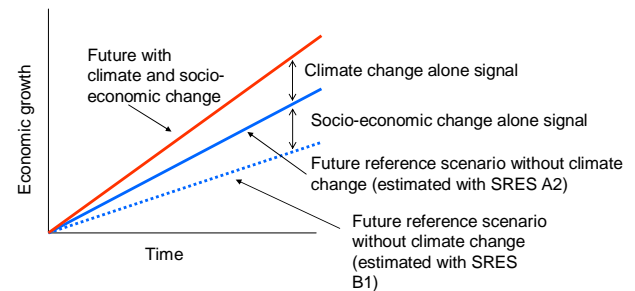


Fig. 1 Estimating the climate and the socio-economic signal

## III. RESULTS AND DISCUSSION

The following sections present a summary of the results of the aggregation of crop productivity changes under the climate scenarios, the resulting changes in the main socio-economic variables, analysing the effects of the climate and the socio-economic signal in the resulting cost of inaction.

### *Aggregation of spatial crop productivity changes*

The physical impacts on agriculture aggregated into agricultural regions are in Figure 2 and 3. The yield changes include the direct positive effects of CO<sub>2</sub> on the crops, the rain-fed and irrigated simulations in each district. Figure 2 and 3 summarises the regional changes in crop yield under the HadCM3/HIRHAM A2 and for the ECHAM4/ RCA3

A2 scenarios respectively for the 2080s compared to baseline. These impacts are in agreement with the biophysical processes simulated with the calibrated crop models, agree with the evidence of previous studies, and therefore have a high confidence level. Based on these change, a series of simulations have been conducted to derive monetary impacts of climate change in the entire European agricultural sector by using GTAP model that considers the production, consumption, and policy.

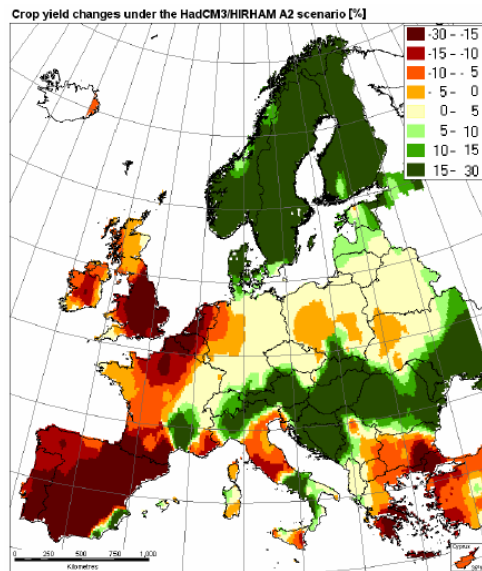


Fig. 2 Average changes in crop productivity under the HadCM3/HIRHAM A2 scenario for the 2080s considering adaptation compared to baseline (% of current crop productivity). Source: PESETA project

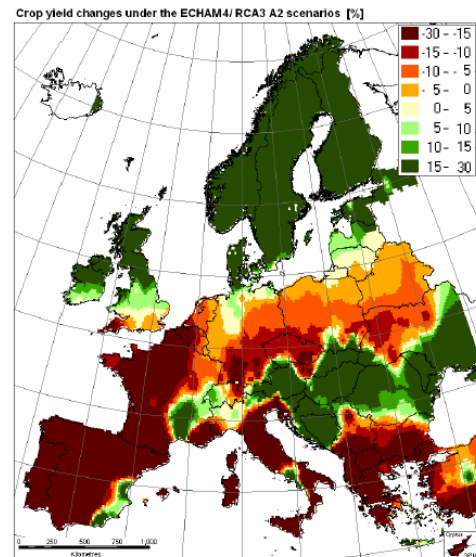


Fig. 3 Average changes in crop productivity under the ECHAM4/RCA3 A2 scenario for the 2080s considering adaptation compared to baseline (% of current crop productivity). Source: PESETA project

#### *Climate signal in socio-economic indicators*

Change in regional GDP resulting directly from the climate change signal is presented in Figure 4. The effects on GDP are smaller than the productivity increases, as usual in general equilibrium simulations, due to the ability of the economy to factors substitution to paliate/potenciate the changes. However, the patterns are consistent with the physical impacts, which are positive except on Mediterranean countries. The most important increases seem to concern the continental region, where the productivity increases enlarge GDP more intensively due to the importance of agricultural sector in the region.

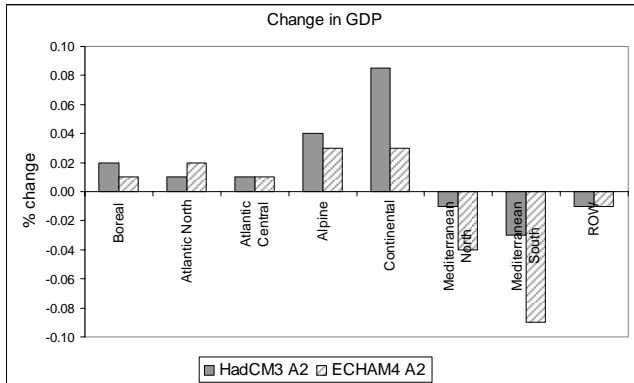


Fig. 4 Average changes in regional GDP under the climate change scenarios.

The crop yield changes presented in Figure 2 and 3 also give rise to changes in world supply. When the entire world is considered, the effects are ambiguous. However, European crop supply change is positive as can be deduced for the trade balance in Figure 5 and 6. Changes in crop imports (Figure 5) and exports (Figure 6) vary relatively more than the changes in GDP and result in decreases in crop prices in most regions under the considered scenarios (Figure 9).

Exports increases and imports are reduced in almost all the European regions, so the crops supply augmenting results in lower crop prices. An exception occurs for the Mediterranean regions where crop productivity negative changes derive into a decrease in crop supply and rising prices.

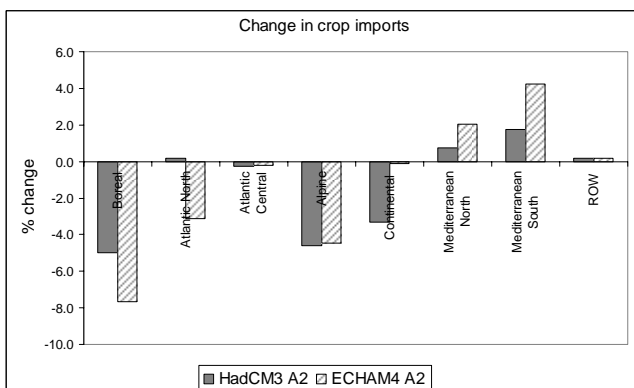


Fig. 5 Average changes in crop imports under the climate change scenarios.

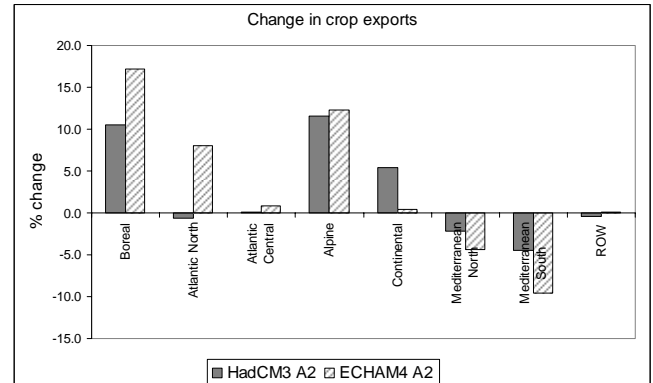


Fig. 6 Average changes in crop exports under the climate change scenarios.

Production factors prices moves in the same sense that marginal productivity, so patterns in capital and labor prices are similar responding to the productivity change. However, the effects are larger in the capital markets due to the population increase that enlarge labor force and mitigate the wages increase.

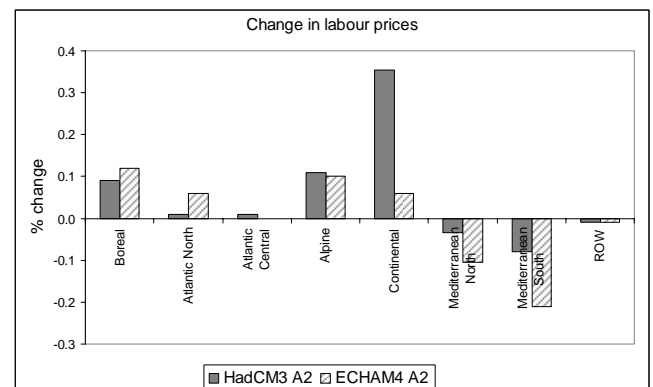


Fig. 7 Average changes in the price of labor under the climate change scenarios.

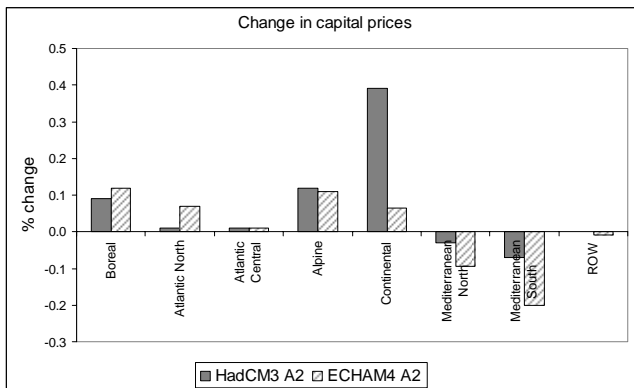


Fig. 8 Average changes in the price of capital under the climate change scenarios.

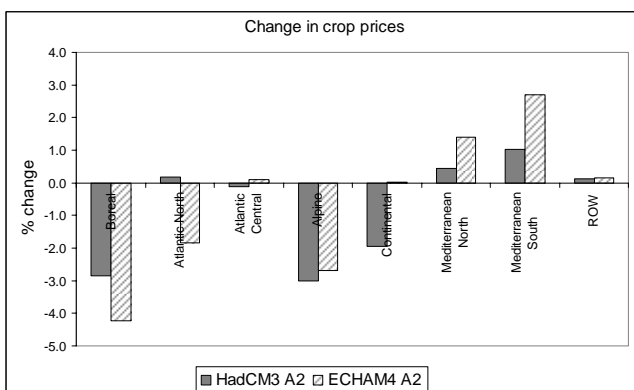


Fig. 9 Average changes in crop prices.

Finally, changes in welfare are largest in the Continental region (Figure 10), responding to the mayor GDP increase.

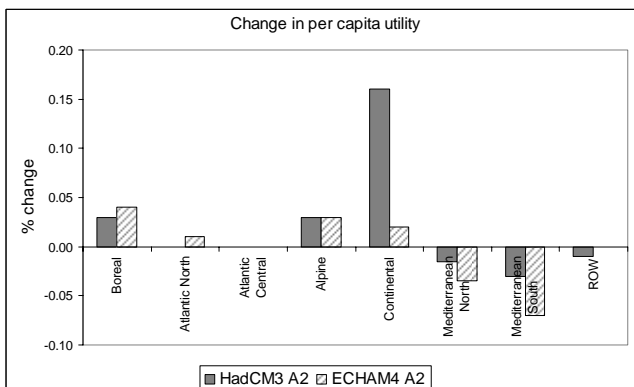


Fig. 10 Average changes in per capita utility.

### *Comparing the climate signal with the socio-economic change impact in the cost of inaction*

The cost of inaction is the difference between the economic results in the best climate future still achievable, and the business-as-usual climate future. Figure 11 show the estimated changes in the value of GDP and world supply under the A2 socio-economic scenario, considered as the business-as-usual future projection with respect to the B1 “no-change” baseline. Agricultural potential savings from taking action to reduce greenhouse gas emissions are possible in all the European regions, being larger in the Atlantic North and Alpine regions. A relative decrease in the European countries population with respect to the rest of the world population (as projected by the population scenarios considered) could produce a relative decrease on the skilled labour in the European countries with respect to the unskilled labour force (due to migrations) and a deviation of resources to less productive sectors as agriculture. This fact could explain the reduction over the total incomes in the European countries under A2 socio-economic scenarios. The monetary estimates show that in all cases the socio-economic signal has a larger effect over economic results than the climate signal. That is relevant since the physical effects studies can not capture this effect, while don't take into consideration the reallocation of factors.

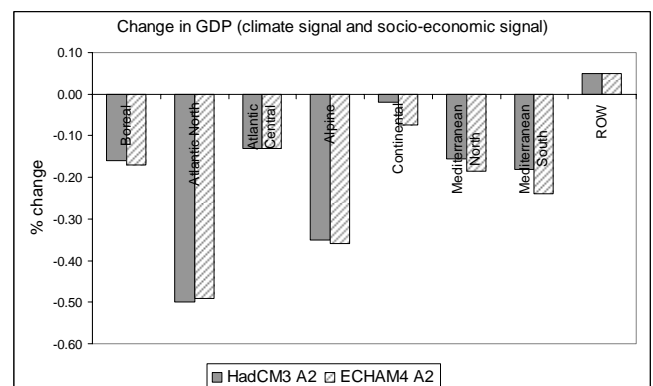


Fig. 11 Agricultural cost of inaction.

#### IV. CONCLUSIONS

This paper provides monetary estimates of the impacts of climate change in European agricultural sector. The estimated changes in the exports and imports of agricultural goods, value of GDP and value of world supply under the climate and socio-economic scenarios show significant regional differences between northern and southern European countries. The patterns are positive effects except on Mediterranean countries. The most important increases seem to concern the continental south region, where the productivity increases enlarge GDP more intensively due to the importance of agricultural sector in the region. Water restrictions and socio-economic variables that modify the probabilities of change occurring may also be considered in further studies. The monetary estimates also show that in all cases the socio-economic signal, including population patterns (such as migrations) has a larger effect over economic results than the climate signal. That is relevant since the physical effects studies can not capture this effect, while don't consider factors reallocation.

#### ACKNOWLEDGMENT

This paper is part of the European Union Joint Research Centre project: "Projection of economic impacts of climate change in sectors of Europe based on bottom-up analysis" (PESETA). Lot 4. Agriculture. Contract Number: 150364-2005-F1ED-ES. <http://peseta.jrc.es/index.htm>.

#### REFERENCES

1. Antle, J.M. and S.M. Capalbo. (2001). Econometric-Process Models for Integrated Assessment of Agricultural Production Systems. *American Journal of Agricultural Economics* 83(2):389-401.
2. Bosello F, Zang J (2005). Assessing climate change impacts: Agriculture. Fondazione Eni Enrico Mattei (FEEM), Italy
3. Conrad C., (2001). Computable general equilibrium models in environmental and resource economics. *Beiträge zur angewandten wirtschaftsforschung* 601-01, Universität Mannheim, Mannheim.
4. Darwin, R., (2004). Effects of greenhouse gas emissions on world agriculture, food consumption, and economic welfare. *Climatic Change* 66, 191-238.
5. Dimaranan, B.V., McDougall, R.A., (2006). Guide to the GTAP Data Base. Global Trade, Assistance, and Production: The GTAP6 Data Base. Dimaranan [ed], Center for Global Trade Analysis. Purdue University.
6. European Commission (2007). Adapting to climate change in Europe options for EU action. Green paper form the commission to the council, the European parliament, the European economic and social committee and the committee of the regions. Brussels.
7. Fankhauser, S. and R.S.J. Tol (2005), On Climate Change and Economic Growth, *Resource and Energy Economics*, 27, 1-17.
8. Gregory, P.J., J.S.I. Ingram, and M. Brklacich, (2005) Climate change and food security. *Philosophical Transactions of the Royal Society B*, 360, 2139-2148.
9. Grubb, M., Köhler, J., and Anderson D., (2002). Induced technical change in energy and environmental modeling: Analytic Approaches and Policy Implications. *Annual Review of Energy and the Environment*, Vol. 27: 271-308.
10. Hertel, T.W., (1997) *Global Trade Analysis: Modelling and Applications*, Cambridge University Press.
11. Iglesias A., L. Garote, F. Flores, and M. Moneo. (2007) Challenges to manage the risk of water scarcity and climate change in the Mediterranean. *Water Resources Management*, 21:227-288.
12. IPCC. (2007). *Climate Change 2007: Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge.
13. Kaiser, H.M., S.J. Riha, D.S. Wilks, D.G. Rossiter, and R. Sampath. (1993). A Farm-Level Analysis of Economic and Agronomic Impacts of Gradual Warming. *American Journal of Agricultural Economics* 75:387-398.
14. Mendelsohn, R., A. Dinar, A. Basist, P. Kurukulasuriya, M.I. Ajwad, F. Kogan, and C. Williams, (2004). Cross-sectional Analyses of Climate Change Impacts. *World Bank Policy Research Working Paper* 3350, Washington, DC.
15. Mendelsohn, R., W. Nordhaus, and D. Shaw. (1999). The impact of climate variation on US agriculture. In *The Impacts of Climate Change on the U.S. Economy*, R. Mendelsohn and J. Neumann (eds.). Cambridge University Press, Cambridge, UK, pp. 55-93.



16. Nicholls, R.J. and R.S.J. Tol (2005), 'Impacts and responses to sea-level rise: A global analysis of the SRES scenarios over the 21st Century', *Philosophical Transaction of the Royal Society A – Mathematical, Physical and Engineering Sciences*, 361 (1841), 1073-1095.
17. Nordhaus, W.D. (2006), 'Geography and Macroeconomics: New Data and New Findings', *Proceedings of the National Academy of Science* ([www.pnas.org/cgi/doi/10.1073/pnas.0509842103](http://www.pnas.org/cgi/doi/10.1073/pnas.0509842103)).
18. Olesen, J., and Bindi, M. (2002). Consequences of climate change for European agricultural productivity, land use and policy. *European Journal of Agronomy* 16, 239-262.
19. Olesen, J.E., and Bindi, M., (2002). Consequences of climate change for European agricultural productivity, land use and policy. *European Journal of Agronomy*, 16, pp. 239-262.
20. Parry MA, Rosenzweig C, Iglesias A, Livermore M, Fischer G (2004) Effects of climate change on global food production under SRES emissions and socio-economic scenarios. *Global Environmental Change* 14 (2004) 53–67
21. Parry ML, C Rosenzweig, A Iglesias, G Fischer (2001). Millions at Risk: Defining Critical Climate Change Threats and Targets *Global Environmental Change*, 11:181-183
22. Parry, M.L., Rosenzweig, C., Iglesias, A., Livermore, M., Fischer, G., (2004). Effects of climate change on global food production under SRES emissions and socio-economic scenarios. *Global Environmental Change*, 14, pp. 53-67.
23. PRUDENCE (Prediction of Regional scenarios and Uncertainties for Defining EuropeN Climate change risks and Effects) <http://prudence.dmi.dk/>
24. Reilly, J., F.N. Tubiello, B. McCarl, D. Abler, R. Darwin, K. Fuglie, S. Hollinger, C. Izaurralde, S. Jagtap, J. Jones, L. Mearns, D. Ojima, E. Paul, K. Paustian, S. Riha, N. Rosenberg, and C. Rosenzweig, (2003). U.S. agriculture and climate change: New results. *Climatic Change*, 57(1), 43-69.
25. Sachs (2001), *Tropical Underdevelopment*, Working Paper 8119, National Bureau of Economic Research, Cambridge.
26. Stern, N., S. Peters, V. Bakhshi, A. Bowen, C. Cameron, S. Catovsky, D. Crane, S. Cruickshank, S. Dietz, N. Edmonson, S.-L. Garbett, L. Hamid, G. Hoffman, D. Ingram, B. Jones, N. Patmore, H. Radcliffe, R. Sathiyarajah, M. Stock, C. Taylor, T. Vernon, H. Wanjie, and D. Zenghelis (2006), *Stern Review: The Economics of Climate Change*, HM Treasury, London.
27. Tol, RSL (2007). The Stern review of the economics of climate change: A comment. *Economic and Social Research Institute Hamburg, Vrije and Carnegie Mellon Universities* November 2, 2006. In Internet: <http://www.fnu.zmaw.de/fileadmin/fnu-files/reports/sternreview.pdf>

Use macro [author address] to enter the address of the corresponding author:

- Author: Sonia Quiroga
- Institute: Universidad de Alcalá
- Street: Plaza de la Victoria, nº 2
- City: Alcalá de Henares, Madrid
- Country: Spain
- Email: [sonia.quiroga@uah.es](mailto:sonia.quiroga@uah.es)